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INFLUENCE OF LIVE WEIGHT, BREED
SEX AND RATION ON TISSUE
DEVELOPMENT IN SWINE

BY



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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled, "Influence of Live Weight, Breed, Sex and Ration on Tissue Development in Swine" submitted by Robert John Richmond in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

A study was conducted to determine the patterns of tissue development and distribution in swine and to assess the effect of live weight, breed, sex and ration on these patterns.

Complete anatomical dissection was carried out on the left side of carcasses of seventy-three pigs taken from an experiment which involved 144 barrows and gilts of Duroc x Yorkshire, Hampshire x Yorkshire and Yorkshire x Yorkshire breeding fed either a high energy (HE) (3652 kcal DE/kg and 19.9% protein) or a low energy (LE) (2757 kcal DE/kg and 15.3% protein) ration for two one-hour periods per day and slaughtered at 68, 91 and 114 kg live weight. Part of the study also included data from 19 Hampshire x Yorkshire barrows and gilts killed at the same live weights but fed the two rations on an ad libitum basis. To establish a starting point 9 barrows and 8 gilts of the same breed groups were slaughtered at 23 kg live weight.

A normal pattern of tissue growth occurred with bone growth being relatively slow and muscle growth relatively fast. Fat deposition paralleled muscle growth up to 91 kg live weight and thereafter exceeded muscle growth in absolute amount. Breed of sire influenced both tissue weights per day of age and the proportions of the tissues in the carcass. The influence of sex and ration were similar. At all slaughter weights, the differences in the proportions of muscle, fat and bone between barrows and gilts paralleled differences resulting from the HE and LE rations.

Muscle distribution changed slightly between 23 and 68 kg live weight but remained constant thereafter. Breed, sex and ration had

little influence on muscle distribution. However, gilts were found to mature at earlier weights than barrows.

Differentiation in fat deposition occurred between depots as live weight increased; % subcutaneous fat increased and % intermuscular and body cavity fat decreased. Within depots a greater proportion of intermuscular and body cavity fat were deposited in the front quarter and a greater proportion of subcutaneous fat in the hind up to 68 kg live weight. Thereafter little differentiation occurred. Certain deviations from this pattern occurred as a result of breed, sex and weight interactions.

The impetus for length and circumference growth in bone was greatest between 23 and 68 kg live weight. During this period growth in circumference was proportionately greater than that in length but thereafter growth impetus was similar. As in muscle distribution, differentiation in bone distribution was essentially completed at or before 23 kg live weight.

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GENERAL INTRODUCTION

Present and projected requirements for pork are for carcasses with high lean to fat ratios. Satisfying this requirement may necessitate the directing of tissue development away from a "normal" toward a "desired" pattern of growth. Before this can be accomplished however, "normal" patterns must be delineated and the influence of genotypic and environmental factors on these patterns must be understood.

Growth patterns of tissues in swine carcasses were studied by Hammond and his students at Cambridge beginning more than thirty years ago. Their studies led to widely accepted theories of growth. A shortcoming of the Cambridge studies was that separation of tissues was by a jointing technique relating butcher's cuts which often grouped together tissues with functional and anatomical differences. Recently total anatomical separation of tissues has been used in an attempt to further clarify tissue growth patterns in several species.

The object of this experiment was to use the anatomical dissection technique to determine the normal development and distribution of the major carcass tissues in swine and evaluate some of the deviations that might occur in these normal growth patterns as a result of some genotypic and environmental effects.

I. Tissue Development

A) Introduction

The means of evaluating carcass composition in domestic animals has varied between the jointing or semi-dissection technique and the more simple, linear measurements and yield of wholesale carcass cuts. Hammond (1932) developed the jointing technique to study the changes in growth within and between carcass tissues in sheep. His findings suggested a differentiation in growth between tissues as well as an anterior-posterior and centripetal pattern of tissue development. Later studies in sheep (Palsson and Verges, 1952; Wallace, 1948) and in pigs (McMeekan, 1940a, b, c, 1941) confirmed these observations and further suggested that a considerable deviation from these patterns of growth could be expected as a result of the influence of breed, sex and ration.

However, because this technique was so laborious researchers adopted the more expedient method of linear measurements and yield of wholesale cuts as a means of studying changes in carcass composition. As a result the literature is now replete with the gross changes in carcass composition that occur due to the influence of live weight, breed, sex and ration.

Several workers (Atkinson and Klein, 1946; Allen et al., 1961; Braude et al., 1963; Brooks et al., 1964; Buck, 1963; McCampbell and Baird, 1961) have indicated that as live weight increases the proportion of muscle in the carcass decreases while fat increases.

Breed and type of pig have been shown to affect carcass composition quite markedly (Aunan et al., 1961; Berg, 1958; King, 1963; King, 1966; Lucas and Calder, 1956; Plank and Berg, 1963; Sayre et al., 1963;

Whiteman et al., 1951).

Differences in carcass composition between sexes noted by Bruner et al. (1958), Self et al. (1957), Robinson (1965) and Zobrisky et al. (1961) have shown gilts to have more muscle and less fat than barrows.

Carcass composition varies in response to ration. Comparisons of low vs high energy rations have indicated that low energy rations produce leaner carcasses than high energy rations (Baird and McCampbell, 1962; Brooks et al., 1963; Jones and Pond, 1964; Wagner et al., 1963).

However, the contribution of these studies to a knowledge of individual tissue growth has been minimal. While gross weight changes are relatively easily measured changes in tissue development can only be studied by a technique of serial slaughtering and complete anatomical dissection. Recently, studies of this nature have begun in cattle (Berg, 1968; Berg and Butterfield, 1968; Butterfield, 1963). But except for the report by Cuthbertson and Pomeroy (1962), which did little more than confirm McMeekan's work (1940a, b, c), no similar studies have been done in swine.

The present chapter reports the results of a study concerned with the growth patterns of muscle, fat and bone tissues and the influence of live weight, breed, sex and ration on these patterns.

B) Materials and Methods

The methods, procedures and experimental design have been previously outlined (Skitsko, 1969; Skitsko and Bowland, 1970) in reports concerning the nutritional aspects of the study. Basically the study

involved 114 barrows and gilts of Duroc x Yorkshire, Hampshire x Yorkshire and Yorkshire x Yorkshire breeding which were fed a standard early weaning ration containing 3500 kcal DE/kg and 20% crude protein from weaning at three weeks until they reached 23 kg live weight. Thereafter they were individually fed either a high energy (HE) (3652 kcal DE/kg and 19.9% protein) or low energy (LE) (2757 kcal DE/kg and 15.3% protein) ration for two one hour periods per day and slaughtered at either 68, 91 or 114 kg live weight. A sample of seventy-three pigs, representing breed, sex and ration effects at each of the 3 slaughter weights were chosen for carcass dissection. An additional nine barrows and eight gilts of the same breed groups were slaughtered at 23 kg live weight to establish a base for carcass composition comparisons. All slaughtering, carcass grading and Record of Performance measuring was done at a local packing plant. The left side of each carcass was returned to the University Meat Laboratory for dissection. Half carcasses were dissected into individual muscles, fat and bone (Butterfield and May, 1965). Fat was separated into subcutaneous (fat + skin), intermuscular and body cavity fat. Loose connective tissue was weighed with fat. Tendon was weighed separately but included with bone in this study.

Statistical analyses of the data involved multiway analyses of variance, mean comparisons and multiple stepwise regression (Steel and Torrie, 1960).

C) Results and Discussion

Normal growth of tissues

In Figure 1 average weight of carcass and individual tissues

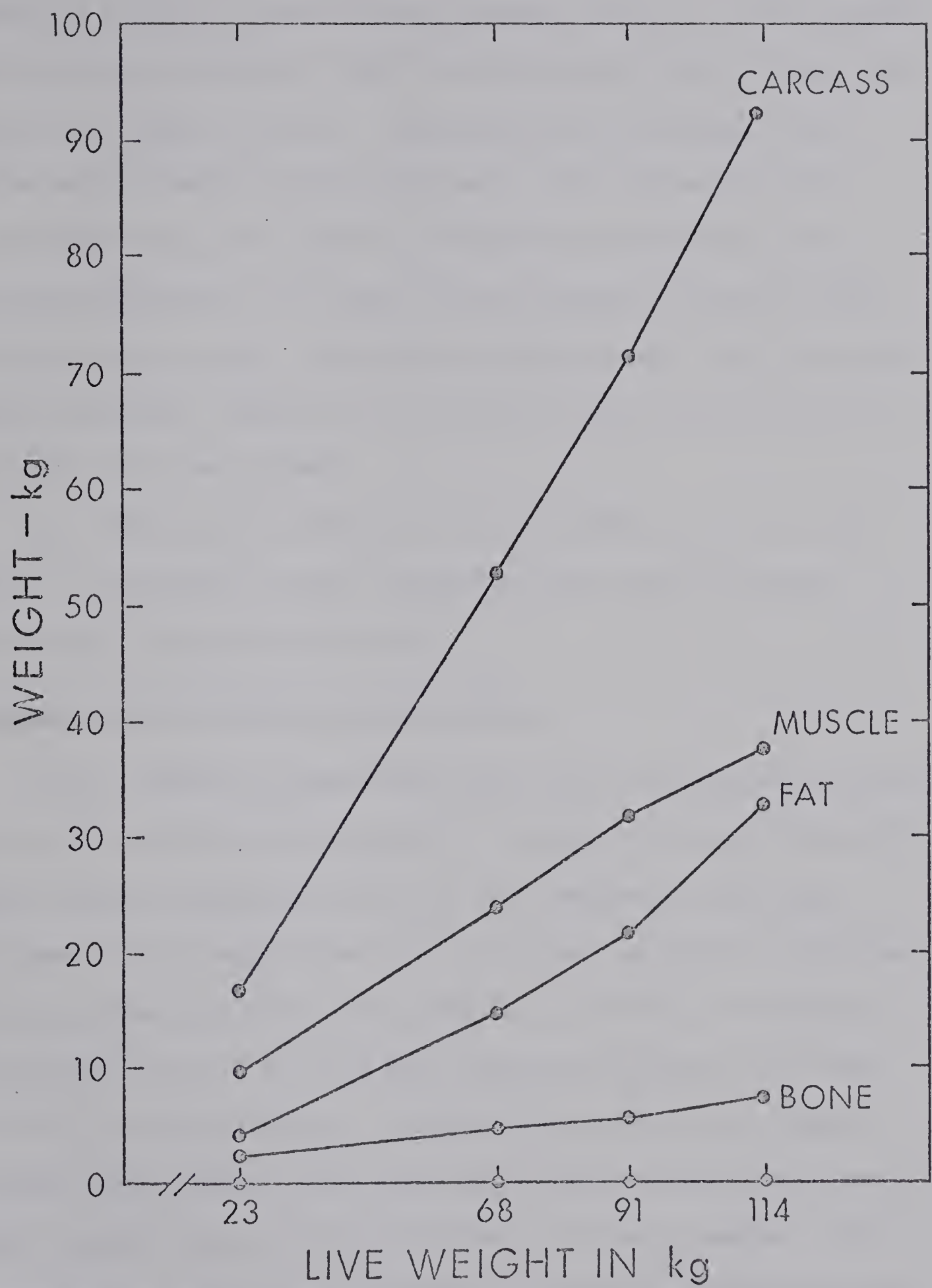


FIGURE 1. CARCASS, MUSCLE, FAT AND BONE WEIGHTS RELATIVE TO LIVE WEIGHT IN PIGS.

(muscle, fat and bone) are plotted relative to live slaughter weight. A definite pattern of tissue growth occurred similar to that observed by Cuthbertson and Pomeroy (1962) in swine, Berg (1968) and Berg and Butterfield (1968) in cattle. Bone grew relatively slowly while muscle had a relatively high growth rate. The decline in muscle growth after 91 kg live weight was offset by the increase in fat deposition resulting in an almost linear increase in carcass weight relative to live weight. Increase in carcass weight after 91 kg live weight was closely related to the increase in fat deposition and is in agreement with Brooks (1964).

Data indicating the influence of live weight, breed, sex and ration on growth rate, carcass composition and various carcass measurements are presented in Table 1.

Influence of live weight on tissue growth

As live weight increased from 23 kg to 114 kg, dressing % increased from 63.3 to 80.2 percent (Table 1). Between 68 kg and 114 kg live weight, backfat increased from 6.4 to 9.2 centimeters ($P < 0.01$). Increases in live weight from 23 kg to 114 kg, resulted in a decrease in percent muscle in the carcass from 60.4 to 48.7%, an increase in percent fat from 25.9 to 42.1% and a decrease in percent bone from 13.2 to 9.2 percent (Table 1). Between 23 and 114 kg live weight, carcass, muscle and fat weights per day of age increased while bone weight per day of age remained relatively constant. However, while carcass and fat weights per day of age increased at increasing rates up to 114 kg live weight, muscle weight per day of age increased at a decreasing rate after 91 kg live weight. Similar changes in carcass

TABLE 1. . Influence of live weight, breed, sex and ration on carcass composition and tissue growth in swine

	LIVE WEIGHT GROUP (kg)						BREED			SEX			RATION	
	23 ¹	68	91	114	DxY		HxY		YxY		Barrows	Gilts	LE	HE
					23	25	23	27	23	27				
No. of animals.....	17	24	24	25	23	23	23	23	27	37	36	35	38	
Age at slaughter.days	75	149 ^a	174 ^b	211 ^c	173 ^a	173 ^a	173 ^a	173 ^a	187 ^b	176	180	191 ^a	165 ^b	
Live weight.....kg	26.6	69.6 ^a	91.9 ^b	115.0 ^c	92.2	92.2	92.4	92.0	92.0	92.5	91.8	92.1	92.3	
Carcass weight.....kg	16.8	52.9 ^a	71.5 ^b	92.2 ^c	73.0 ^a	73.0 ^a	72.5 ^b	71.1 ^c	71.1 ^c	72.3	72.1	70.6 ^a	73.8 ^b	
Dressing.....%	63.3	76.1 ^a	77.8 ^b	80.2 ^c	78.8 ^a	78.8 ^a	78.2 ^a	77.0 ^b	77.0 ^b	77.8	78.1	76.3 ^a	79.7 ^b	
Total backfat. ²cm	----	6.4 ^a	7.3 ^b	9.2 ^c	7.9	7.9	7.3	7.8	7.8	8.1 ^a	7.2 ^b	7.1 ^a	8.2 ^b	
Grade.....%	----	88 ^a	103 ^b	85 ^c	91	91	92	92	92	91	92	92	92	
CARCASS COMPOSITION														
Muscle.....kg	9.4	23.9 ^a	31.7 ^b	37.7 ^c	30.7	32.2	32.2	30.4	30.4	29.6 ^a	32.6 ^b	32.3 ^a	30.0 ^b	
Fat.....kg	4.1	14.6 ^a	21.8 ^b	32.8 ^c	23.8	22.1	22.1	23.2	23.2	24.7 ^a	21.4 ^b	20.9 ^a	25.1 ^b	
Bone.....kg	2.1	4.5 ^a	5.6 ^b	7.1 ^c	5.7	5.8	5.8	5.9	5.9	5.6	6.0	5.9	5.8	
Muscle.....%	60.4	55.7 ^a	53.5 ^b	48.7 ^c	51.7	54.3	54.3	51.8	51.8	50.2 ^a	55.0 ^b	55.1 ^a	50.1 ^b	
Fat.....%	25.9	33.8 ^a	36.7 ^b	42.1 ^c	38.6	35.9	35.9	38.1	38.1	40.1 ^a	34.9 ^b	34.8 ^a	40.3 ^b	
Bone.....%	13.2	10.5 ^a	9.9 ^b	9.2 ^c	9.7	9.7	9.7	10.1	10.1	9.6	10.1	10.1	9.6	
Muscle-bone ratio.....	4.6	5.3	5.4	5.3	5.4	5.6	5.6	5.1	5.1	5.3	5.5	5.5	5.2	
GROWTH/DAY OF AGE														
Live.....g	354	473 ^a	533 ^b	550 ^c	535 ^a	532 ^a	532 ^a	489 ^b	489 ^b	529 ^a	508 ^b	478 ^a	559 ^b	
Carcass.....g	275	361 ^a	415 ^b	441 ^c	425 ^a	416 ^a	416 ^a	377 ^b	377 ^b	413 ^a	398 ^b	366 ^a	448 ^b	
Muscle.....g	118	163 ^a	183 ^b	179 ^c	177 ^a	185 ^b	185 ^b	161 ^c	161 ^c	170 ^a	180 ^b	167 ^a	182 ^b	
Fat.....g	54	99 ^a	126 ^b	157 ^c	136 ^a	126 ^b	126 ^b	121 ^c	121 ^c	139 ^a	116 ^b	106 ^a	149 ^b	
Bone.....g	27	31	34	34	33	33	33	32	32	32	33	30 ^a	35 ^b	
Feed conversion kg/kg	.39	3.01	3.06	3.38	3.15	3.04	3.04	3.26	3.26	3.19	3.11	3.58 ^a	2.72 ^b	

1 Means for pigs slaughtered at 23 kg not included in statistical comparisons.

2 Total of 3 measurements.

a,b,c, means within the same classification having different superscripts, differ significantly at $P < 0.05$ or $P < 0.01$.

composition and the influence of fat deposition on dressing % have also been indicated by other workers (Bowland and Berg, 1959; Braude et al., 1963; Brooks et al., 1964; Buck, 1963; Cuthbertson and Pomeroy, 1962; McCampbell and Baird, 1961; Wagner et al., 1963). By 91 kg live weight pigs had 84% of the muscle and 66% of the fat that was present at 114 kg live weight.

Influence of breed on tissue growth

Although comparisons were made among breed groups it should be noted that these were not intended to be specific for the breeds studied. Hampshire x Yorkshire and Duroc x Yorkshire pigs were cross-breeds while Yorkshire x Yorkshire pigs were purebreds. Gain and carcass traits may have been influenced by heterosis and its importance could not be assessed in this experiment.

There were no significant differences in total muscle, fat or bone weights or percentages among breeds at 68, 91 or 114 kg live weights (Table 1). Yorkshire x Yorkshire pigs were older (187 days) than Duroc x Yorkshire or Hampshire x Yorkshire pigs which were equal (173 days) in age at slaughter. Hampshire x Yorkshire pigs had a greater weight of muscle per day of age ($P < 0.01$) than did either Duroc x Yorkshire or Yorkshire x Yorkshire pigs but were intermediate in fat per day of age. Duroc x Yorkshire and Hampshire x Yorkshire pigs had greater ($P < 0.01$) live weight and carcass weight per day of age than did Yorkshire x Yorkshire pigs. Duroc x Yorkshire pigs also had the greatest fat per day of age ($P < 0.01$). Although no differences in feed conversion between breeds were observed here, analyses of the entire experiment (Skitsko and Bowland, 1970) indicated that Duroc x

Yorkshire and Hampshire x Yorkshire pigs were more efficient in feed conversion than Yorkshire x Yorkshire and that Duroc x Yorkshire pigs consumed more feed per day on the HE ration than on the LE ration.

Influence of sex and ration on tissue growth

Gilts had less ($P < 0.01$) backfat, carcass fat and percentage fat and more ($P < 0.01$) carcass muscle and percentage muscle than did barrows (Table 1). Muscle-bone ratio and bone weight were similar for each sex. Live weight, carcass weight and fat per day of age were less for gilts than for barrows ($P < 0.05$). Gilts had more muscle per day of age than did barrows ($P < 0.05$). Differences in feed conversion for the seventy-three barrows and gilts which were dissected were not significantly different (3.19 and 3.11 kg feed/kg gain for gilts and barrows respectively). However, data for the entire experiment (Skitsko and Bowland, 1970), indicated that gilts required less feed/kg gain than did barrows.

Pigs fed the LE ration were 26 days older at slaughter than pigs fed the HE ration ($P < 0.01$) (Table 1). Carcass weight, dressing % and total backfat were respectively 3.2 kg, 3.4% and 1.1 cm greater ($P < 0.01$) for the HE fed pigs over those fed the LE ration. Because of the difference in age to slaughter between the HE and LE ration (165 vs. 191 days) pigs fed the HE ration had a greater weight per day of age for all measurements than did those fed the LE ration ($P < 0.05$). Feed conversion favored the HE ration over the LE ration (2.72 vs. 3.58 kg feed/kg gain) ($P < 0.01$).

Differences in carcass composition between ration groups were similar to differences between sexes. Figure 2 illustrates the

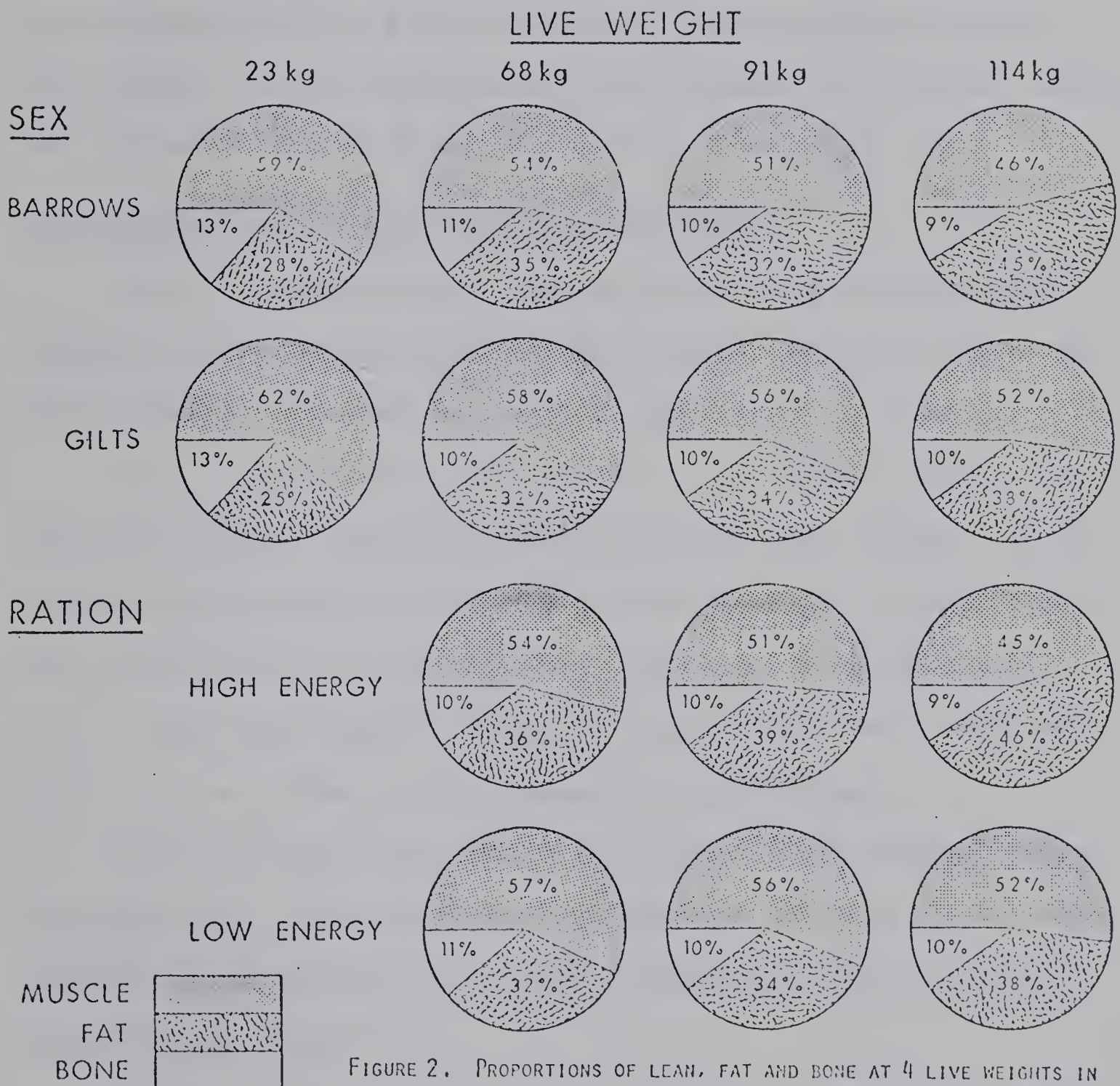


FIGURE 2. PROPORTIONS OF LEAN, FAT AND BONE AT 4 LIVE WEIGHTS IN CARCASSES FROM BARROWS AND GILTS AND HIGH ENERGY AND LOW ENERGY RATIIONS.

similarity of sex and ration effects on percentage muscle, fat and bone at 23, 68, 91 and 114 kg live weight. In each case as live weight increased percent muscle decreased, percent fat increased and percent bone decreased slightly. Gilts had a slightly greater percent of muscle and less of fat at 114 kg live weight than did barrows at 91 kg live weight. Carcass composition for LE fed pigs at 114 kg live weight was similar to that of HE fed pigs at 91 kg live weight.

Live weight, breed, sex and ration interactions

The data revealed several two-way interactions among the major effects of live weight, breed, sex and ration. Those at or above the 5% significance level are presented in Tables 2, 3, 4, 5 and 6.

Table 2 presents the interaction of live slaughter weight by sex and live slaughter weight by ration on carcass grade indexes. At 91 kg live weight gilts were superior to barrows in grade indexes (105 vs. 102) and pigs fed the LE ration were superior to those fed the HE ration while carcass grade indexes for pigs slaughtered at 68 kg and 114 kg did not reflect carcass composition differences.

On the LE ration both barrows and gilts reached slaughter weight at similar ages (192 and 190 days respectively) while on the HE ration barrows reached market 11 days earlier than gilts (159 vs. 170 days respectively) (Table 3).

Gilts on the LE ration had more muscle per day of age, a greater final weight and slightly greater carcass weight per day of age than did barrows. On the other hand, barrows on the HE ration were equal to gilts in muscle per day of age but had a greater final weight and carcass weight per day of age than did gilts (Tables 3, 4, 5).

Each of these sex by ration effects on carcass composition were

TABLE 2: Mean carcass grade indexes (%) as influenced by interactions of slaughter weight by sex and slaughter weight by ration

Slaughter weight	SEX		RATION	
	Barrows	Gilts	LE	HE
68	89	87	87	89
91	102	105	105	102
114	84	86	86	84

TABLE 3: Slaughter age (days) and muscle per day of age (g) as influenced by interaction of sex by ration

Characteristic	Sex	RATION	
		LE	HE
Slaughter age (days)	Barrows	192	159
	Gilts	190	170
Muscle per day of age (g)	Barrows	159	182
	Gilts	182	182

TABLE 4: Final weight per day of age (g) as influenced by breed by sex and ration by sex interactions

Sex	BREED			RATION	
	D	H	Y	LE	HE
Barrows	533	561	494	475	584
Gilts	536	503	483	481	534

TABLE 5: Carcass weight per day of age (g) as influenced by breed by ration and sex by ration interactions

Ration	BREED			SEX	
	D	H	Y	Barrows	Gilts
LE	371	379	346	363	369
HE	474	454	409	464	428

TABLE 6: Fat per day of age (g) as influenced by breed by sex interaction

Sex	BREED		
	D	H	Y
Barrows	147	145	125
Gilts	124	107	117

a reflection of the sex by ration interactions for feed conversion reported by Skitsko and Bowland (1970). Barrows on the LE ration had less efficient feed conversion than gilts but were equal to gilts on the HE ration.

In all three breed groups those pigs fed the HE ration had a greater carcass weight per day of age than those fed the LE ration. However, breed groups ranked differently on the two rations (Table 5). On the LE ration, Hampshire x Yorkshire pigs had greater carcass weight per day of age followed by Duroc x Yorkshire and Yorkshire x Yorkshire pigs. On the HE ration Duroc x Yorkshire pigs were followed by Hampshire x Yorkshire and then Yorkshire x Yorkshire pigs.

As with the barrow-gilt comparisons, pigs with an inherent pre-disposition to lean growth grew faster on the LE ration while pigs with a predisposition to fatten appeared to grow faster on the HE ration.

In the breed by sex interaction (Table 6) gilts from each breed had less fat per day of age than did barrows but breed group ranking differed with the sex of pig compared. Duroc x Yorkshire barrows had similar fat per day of age to Hampshire x Yorkshire barrows and both groups had more fat per day of age than Yorkshire x Yorkshire barrows. Hampshire x Yorkshire gilts had the least fat per day of age followed by Yorkshire x Yorkshire and Duroc x Yorkshire gilts.

Application to performances testing and carcass grading

The data presented here indicate that the normal pattern of tissue development in swine can be altered markedly in the influence of breed, sex and ration.

In testing programs designed to evaluate pigs for rate of gain and carcass composition, different results could arise if using a HE vs. a LE ration because of genotype by ration interactions. Interactions of this nature were reported by Plank and Berg (1963) and Salmela et al. (1963) when comparing progeny groups on liberal vs. limited feeding regimes. The data from this experiment indicated the need for determining carcass composition in performance testing programs designed to identify superior breeding stock. Both Duroc x Yorkshire and Hampshire x Yorkshire had similar live and carcass weights per day of age but whereas this weight was made up by a greater fat per day of age in the Duroc x Yorkshire pigs the increase in the Hampshire x Yorkshire pigs was attributable to a greater weight of muscle per day of age. When comparing breed, sex and ration interactions it was found that the leaner Hampshire x Yorkshire pigs and gilts grew more quickly than the other groups on the LE ration while the fatter Duroc x Yorkshire pigs and barrows grew more quickly on the HE ration.

The fact that genotype environment interactions exist is justification for concern in pig testing programs. However, from the standpoint of the pig producer, the ability to manipulate carcass composition could mean a greater flexibility in the face of fluctuating markets. One of the deterrents to such action at the moment is that the Canadian marketing system operates within the carcass weight range of 56.4 to 81.8 kg carcass weight corresponding to approximately 75 to 100 kg live weight. There are several reports which suggest that pigs slaughtered at both 68 and 114 kg live weight can be produced and processed efficiently and economically and still meet consumer desires

(Bellis and Taylor, 1961; Brooks et al., 1964; Field et al., 1961; Varney et al., 1962). Results from the present experiment suggest that acceptable carcass composition can be obtained at 68 kg and 114 kg live weight. It would seem appropriate to evaluate factors involved in the processing of pig carcasses outside the present accepted weight range with a view to offering a greater variety of pork products. Thus gilts, pigs fed LE rations or strains of pigs with a predisposition to lean growth might be fed to heavier weights. Similarly on the other end of the scale, lighter carcasses from barrows, pigs fed the HE rations or strains of pigs with a predisposition to fat growth might find a more acceptable market.

II. Muscle Growth and Distribution

A) Introduction

The study of tissue development and distribution in the carcass has been primarily done by the use of jointing techniques. Only recently in cattle and swine has tissue distribution been studied by anatomical dissection (Berg and Butterfield, 1968; Butterfield, 1963a, b; Butterfield, 1965; Butterfield and Berg, 1966; Cuthbertson and Pomeroy, 1962).

In this study anatomical dissection of pig carcasses confirmed many of the earlier, less detailed studies of tissue development and revealed several changes that might occur due to the influence of genotype-environment effects. As live weight increased percentage muscle and bone in the carcass decreased and percentage fat increased. Breed of sire influenced the muscle weight per day of age and percent muscle in the carcass. Gilts had more muscle per day of age and a greater percentage of muscle than did barrows. A low energy ration resulted in a higher percentage of muscle in the carcass than did a high energy ration.

Because of these major effects on the percentage of muscle in a carcass the question arose as to whether compositional changes were due to a uniform change in total muscle or to a difference in muscle distribution in the carcass. Recent muscle dissection studies in cattle (Berg, 1968; Butterfield and Berg, 1966) had shown that muscle distribution was relatively constant and that individual muscles grew in either mono- or diphasic patterns but no similar studies had been reported in swine.

The present chapter reports the results of this study concerned with muscle distribution in pigs and the influence of live weight, breed, sex and ration on differential muscle growth.

B) Materials and Methods

The design and allotment of animals was the same as previously presented. In this study data from an additional 19 Hampshire x Yorkshire barrows and gilts were added to that of the 90 pigs previously studied. These additional pigs were slaughtered at the same live weights but were fed the high and low energy rations on an ad libitum basis rather than at two one hour intervals per day. A multiway analysis of variance indicated that there were no significant differences in muscle growth or distribution between the ad libitum and hourly-fed Hampshire x Yorkshire pigs and their data were therefore included in the present analyses.

Half carcasses were dissected into individual muscles, fat and bone using the technique of Butterfield and May (1965). Individual muscles were grouped into 9 "standard muscle groups" (Butterfield, 1963a, b) and those muscle groups representing the expensive carcass cuts were combined into 3 "expensive muscle groups". Group A (ham) consisted of proximal and distal pelvic limb; group B (ham + loin) consisted of proximal and distal pelvic limb and spinal muscles; group C (ham + loin + shoulder) consisted of proximal and distal pelvic limb, spinal and proximal thoracic limb.

Multiway analysis of variance and comparison of means for the data were carried out according to the methods of Steel and Torrie (1960).

C) Results

Live weight had little effect on percentage muscle in the nine muscle groups (Table 7) although pigs slaughtered at 91 kg live weight appeared to have a significantly greater percentage of muscle in muscle group 9 (neck and thorax) than those slaughtered at 68 kg live weight ($P < 0.05$).

Breed differences existed in muscle group 3 (spinal) with Duroc x Yorkshire pigs having a greater percentage of spinal muscle than Hampshire x Yorkshire or Yorkshire x Yorkshire pigs. Percentage of muscle in all other muscle groups were similar for all breeds.

No explanation for either of these live weight or breed differences was readily available except that for breed the greater percentage of spinal muscle in the Duroc x Yorkshire pigs may have been a result of a greater degree of intramuscular fat.

Differences in muscle distribution due to the influence of sex varied relative to live weight. At live weights above 68 kg, differences observed at 23 kg either disappeared or reversed between barrows and gilts. Table 7 shows the sex comparisons between 68 and 114 kg live weight while Table 8 presents those muscle groups found to be significantly different between barrows and gilts at 23 kg live weight.

At 23 kg live weight (Table 8) gilts had 2.12% more muscle in muscle Group 1 (proximal pelvic limb), 0.78% more muscle in muscle group 3 (spinal) and 2.10, 2.96 and 2.87% in expensive muscle groups A, B and C respectively than did barrows. On the other hand barrows had 1.25% more muscle group 9 (neck and thorax) than did gilts.

However, as live weight increased (Table 7) differences between barrows and gilts were no longer present in muscle groups 1 and 9

TABLE 7: "Standard muscle groups" as percentage of weight of total side muscle in barrows and gilts of three breeds fed low and high energy rations and slaughtered at four live weight:

MUSCLE GROUP	LIVE WEIGHT (kg)					BREED			SEX			RATION	
	23 ⁽¹⁾	68	91	114	D	H	Y	Barrows	Gilts	LE	HE		
1. Proximal Pelvic limb	26.56	28.40	28.25	28.67	28.39	28.42	28.50	28.67	28.21	28.42	28.46		
2. Distal pelvic limb	3.99	3.96	3.84	3.87	3.86	3.84	3.97	3.84	3.95	3.81 ^a	3.98 ^b		
3. Spinal	16.83	17.01	17.42	17.44	17.69 ^a	17.17 ^{a,b}	17.01 ^b	17.54 ^a	17.05 ^b	17.32	17.26		
4. Abdominal	12.41	11.32	10.98	11.16	11.16	11.21	11.10	11.22	11.09	11.05	11.26		
5. Proximal thoracic limb	12.35	12.29	12.05	11.79	11.87	11.94	12.32	11.90	12.18	12.08	12.00		
6. Distal thoracic limb	2.15	1.94	1.89	1.85	1.88	1.89	1.91	1.84 ^a	1.95 ^b	1.89	1.90		
7. Thorax to thoracic limb	7.35	7.56	7.64	7.38	7.42	7.57	7.58	7.48	7.57	7.48	7.57		
8. Neck to thoracic limb	4.39	4.90	4.84	4.97	4.88	4.91	4.92	4.77	5.03	4.94	4.87		
9. Neck and thorax	9.28	9.39 ^a	10.02 ^b	9.76 ^{a,b}	9.66	9.81	9.69	9.66	9.78	9.85	9.60		
10. Scrap	4.69	3.21	3.06	3.08	3.15	3.20	3.01	3.07	3.17	3.15	3.09		
Expensive groups:													
A	30.61	32.36	32.09	32.54	32.25	32.27	32.48	32.50	32.16	32.23	32.43		
B	47.46	49.38	49.51	49.98	49.95	49.44	49.48	50.04 ^a	49.20 ^b	49.55	49.70		
C	59.81	61.67	61.56	61.78	61.82	61.38	61.80	61.94	61.39	61.63	61.70		

A (Group 1 + Group 2).
 B (Group 1 + Group 2 + Group 3).
 C (Group 1 + Group 2 + Group 3 + Group 5).
 a,b,c, means within the same classification having different superscripts, differ significantly at P<0.05.
 (1) 23 kg group not tested statistically against other weight groups.

TABLE 8: Muscle group percentages differing significantly between barrows and gilts slaughtered at 23 kg liveweight

Muscle Groups	Barrows	Gilts
1) Proximal pelvic limb	25.56	27.68**
3) Spinal	16.46	17.24*
9) Neck and thorax	9.87*	8.62
Expensive Groups:		
A	29.56	31.66**
B	46.02	48.98**
C	58.37	61.24**

* Significant at $P < 0.05$, ** significant at $P < 0.01$.

or expensive muscle groups A and C. Differences in muscle group 3 and expensive muscle group B were reversed at the heavier live weights with barrows having higher percentages than gilts.

The influence of ration on muscle distribution shown in Table 7 appeared to be limited to muscle group 2 (distal pelvic limb). Those pigs fed the HE ration had a greater percentage of muscle in this group than did those fed the LE ration ($P < 0.05$). All other muscle groups were similar between rations.

Significant ($P < 0.05$) interactions observed between sex and ration and sex and breed in muscle group 7 (thorax to thoracic limb) are presented in Table 9. On the LE ration barrows had a greater percentage of muscle from thorax to thoracic limb than did gilts while gilts had a greater percentage of muscle in this group on the HE ration. Duroc x Yorkshire barrows had a greater percentage of muscle in this muscle group than did gilts while the reverse of this was true for the Hampshire x Yorkshire and Yorkshire x Yorkshire barrows and gilts.

D) Discussion

Some reports have suggested that the differences found in the percentage of muscle in a carcass due to the influence of genetic and environmental factors were expressed in a variation in muscle differentiation and distribution. The more recent anatomical work in cattle by Berg (1968), Berg and Mukhoty (1970), Butterfield (1965) and Butterfield and Berg (1966) has shown that after 3 months of age there is little further muscle differentiation or variation in muscle distribution.

Data presented in this report indicated that, in pigs, muscle

TABLE 9: Percentages in muscle group 7 (thorax to thoracic limb)
showing interactions of sex by ration and sex by breed ($P < 0.05$)

Sex	Ration			Breed		
	LE	HE		D	H	Y
Barrows	7.52	7.44		7.65	7.43	7.37
Gilts	7.44	7.70		7.20	7.72	7.79

differentiation was essentially completed at or before 23 kg live weight and thereafter the percentage of muscle in each of the 9 standard muscle groups remained relatively constant. A review of data presented by McMeekan (1940a) (Table 10) indicated a similar pattern. As can be seen from the table inconsistent variations in muscle percentage in each of the joints occurred between 1.3 kg and 13.2 kg live weight. From 36.1 kg to 100 kg live weight the percentage muscle in each joint was relatively constant.

Differences in certain breeds and types of animals have often been credited to differences in muscle distribution. However, studies of muscle distribution in cattle by Butterfield (1965) indicated no differences among breeds in percentage muscle in the 9 standard muscle groups. When comparing beef-type and dairy-type animals Berg and Mukhoty (1970) found muscle distribution to be similar among types.

In pigs, Bull and Longwell (1929) compared carcasses from "Chuffy", "Intermediate" and "Rangy" type pigs but could find no difference in percentage total muscle among types when compared on a fat free basis. Further calculations of their data for the primal cuts were made to compare muscle distribution among the three types of pigs (Table 11). "Rangy" type pigs had a slightly greater percentage of muscle in the ham and less in the belly than the "Chuffy" type, otherwise the distribution was quite similar among types. In the present data (Table 7) Duroc x Yorkshire pigs which had the most fat were similar in muscle distribution to Hampshire x Yorkshire pigs which had the least fat.

From these studies it appears that, regardless of the conformation or breed of pig, muscle distribution remained relatively constant.

TABLE 10: Muscle distribution in joints of pigs of varying ages as calculated from McMeekan (1940a)

Age.....weeks	Birth	4	8	16	20	24	28
No. of animals..	2	2	1	2	2	3	1
Live weight...kg	1.3	5.9	13.2	36.1	52.1	71.4	100.0
MUSCLE.....%							
Shoulder.....	29.53	23.65	26.77	21.98	20.54	21.20	20.01
Neck.....	11.92	9.46	8.27	8.09	9.14	8.92	8.10
Thorax.....	21.13	25.24	21.95	24.01	24.16	24.21	25.76
Loin.....	8.94	9.95	9.01	12.43	10.90	11.11	12.67
Pelvis and leg..	28.45	31.68	33.98	33.46	35.23	34.54	33.44

TABLE 11: Muscle distribution expressed as a percentage of total primal muscle in three types of pigs as calculated from Bull and Longwell (1929)

Pig type	Chuffy	Intermediate	Rangy
Live weight..kg	102.3	102.3	102.3
Muscle.....%			
Ham.....	18.06	18.63	19.80
Picnic.....	6.98	6.76	7.22
Boston.....	9.13	10.66	10.43
Loin.....	16.45	16.75	16.48
Belly.....	10.22	10.11	8.81

Selecting for types and breeds of pigs with higher percentages of ham and loin would appear to have been without success although a further understanding of the growth impetus of individual muscles and muscle groups may allow for greater progress in this direction.

Muscle differentiation between sexes occurred at or before 23 kg live weight. Gilts had more muscle in the proximal pelvic limb, spinal group and expensive muscle groups A, B and C. Barrows had more muscle in the neck to thorax muscle group. At live weights above 23 kg these differences either disappeared or reversed in significance with barrows having the greater spinal muscle and expensive muscle group B and gilts the greater muscle in the distal thoracic limb group. Comparing these sex influences on muscle development to those in cattle indicated that these observations may be unique to the pig, since in cattle (Berg and Mukhoty, 1970) heifers produced the greater percentage of proximal hind muscles and steers the greater percentage of neck muscle. However the pigs studied here were essentially prepubertal while the cattle studies all extended well past puberty.

The observed changes in muscle distribution at heavier weights between the sexes suggests that muscle growth differentiation in barrows is somewhat more prolonged than in gilts. At 23 kg live weight gilts appear to have a more mature pattern of muscle distribution than do barrows. By 23 kg live weight, gilts had essentially reached the proportions found at later stages while muscle distribution in barrows was still adjusting.

Although energy intake was shown to affect the rate of certain tissue development there was little evidence of variation in distribution of this tissue within the carcass. A review by Elsley, et al.

(1964) of McMeekan's work (1940a, b, c) had indicated that on a fat free basis the differences in relative proportions of bone and muscle in different parts of the body resulting from plane of nutrition were very small. Results from the present study agree with this observation in that distribution of muscle is not affected to any great degree by plane of nutrition.

Interactions between sex and ration and sex and breed were observed in muscle group 7 (thorax to thoracic limb). On the LE ration barrows had a greater percentage of muscle in this muscle group than did gilts, while gilts had the greater percentage of muscle in this group on the HE ration. In the sex by breed interaction in this report Duroc x Yorkshire barrows had a greater percentage of muscle in muscle group 7 than did gilts while the reverse was true between barrows and gilts of Hampshire x Yorkshire and Yorkshire x Yorkshire breeding. In an attempt to explain these differences a comparison of the growth patterns for the 9 standard muscle groups from this data were made with those derived from cattle (Berg, 1968; Butterfield, 1965; Butterfield and Berg, 1966) and are presented in Table 12.

In the original classification of the muscle groups by growth rates, "high" represented a growth rate greater than that for total muscle, "average" a rate comparable to total muscle and "low" a rate less than that for total muscle. In classifying the present data any muscle group that increased in percentage of muscle between 23 kg live weight and heavier weights were classed as "high", a comparable percentage at all weights as "average" and a decrease in percentage between 23 kg live weight and heavier weights as "low".

Muscle group 7 (thorax to thoracic limb) is shown in Table 6 as

TABLE 12: Comparison of standard muscle group growth patterns from previous studies with cattle and the present study with pigs

Species		Cattle			Pigs
Study		Butterfield (1965)	Butterfield and Berg (1966)	Berg (1968)	(present data)
1. Proximal pelvic limb	late	high-average or low	high-average or low	high-average or low	high-average
2. Distal pelvic limb	early	low	low	high-low	average
3. Spinal	average	average	average	high-average	high-average
4. Abdominal	late	high-average or high	high-average or high	high-average or high	low-average
5. Proximal thoracic limb	early	low-average	low-average	low-average	low
6. Distal thoracic limb	early	low-average or low	low-average or low	low-average or low	low
7. Thorax to thoracic limb	very late	high	high	high	average
8. Neck to thoracic limb	very late	average-high	average-high	average-high	high-average
9. Neck and thorax	very late	low-average	low-average	low-average	average

very late developing or of high impetus in cattle but of only average impetus in the present data. The differences in growth rate observed in the sex by ration and sex by breed interactions for this muscle group therefore seem to be still unresolved since the interaction effects tended to indicate a more differentiated rate of growth than is suggested by an average classification. Any sound reason for this difference will probably only emerge when the growth coefficients for the individual muscles within this muscle group are calculated.

The remaining muscle group growth patterns indicated that the growth impetus for muscles in pigs at or above 23 kg live weight was somewhat different than for those in cattle. After the initial adjustment from 23 kg to 68 kg live weight in pigs, muscle distributions remained quite constant. In cattle, some muscle groups continued to differentiate at heavier weights, showing a lower or higher impetus than total muscle. Some of these patterns in cattle were sex influenced following puberty. The pigs in this study were probably less mature physiologically and therefore would not exhibit sex influences that might arise at heavier weights. Nevertheless, the relative constancy of muscle distribution at live weights on either side of normal market weights and among sexes, breed groups and ration energy levels, would support the contention by Tulloh (1963) that selection should be directed towards changes in fat deposition rather than muscle distribution in any performance testing program where improved carcass composition is the goal.

III. Fat Distribution

A) Introduction

Although it has been shown that muscle distribution is relatively constant in the carcass and that fat is the major contributor to differences in carcass composition (Elsley et al., 1964; Fowler, 1967; Hammond, 1932; Tulloh, 1963; Wallace, 1948; Wilson, 1960) only a few experiments have been conducted to study the distribution of fat in the carcass. Hammond (1932) indicated a growth gradient pattern of fat deposition similar to that of muscle. Callow (1947, 1948) and Schon and Schon (1964) reported some major differences within and between species in deposition of subcutaneous and intermuscular fat, while later reports have dealt with environmental and genetic influences on fat deposition in cattle (Callow and Searle, 1961; Ledger, 1959) and with some relationships between subcutaneous and total body fat in swine (Doornenbal, 1967; Duniec et al., 1961).

Because selection in pigs for carcass merit is determined primarily on backfat thickness, it is becoming increasingly important to know what the normal pattern of fat distribution is over varying live weights and how this pattern may be affected by different breeds, sexes and varying planes of nutrition.

The present chapter reports some effects of live weight, breed, sex and ration on fat distribution in the subcutaneous, intermuscular and body cavity depots in pigs.

B) Materials and Methods

A description of the animals used and the design of the experiment was the same as that previously reported.

Half carcasses were divided at the 11th and 12th rib and dissected into individual muscles, fat depots and bones. Fat was separated by front or hind quarter into subcutaneous, intermuscular or body cavity fat.

Multiway analyses of variance and comparison of means for the data were done according to methods of Steel and Torrie (1960).

C. Results

Table 13 shows the growth patterns for subcutaneous fat, intermuscular fat and body cavity fat as a percentage of total carcass fat in pigs slaughtered at 23, 68, 91 or 114 kg live weight. As live weight increased from 23 to 114 kg, % subcutaneous fat increased, % intermuscular fat decreased and % body cavity fat decreased between 23 and 68 kg live weight and then remained relatively constant to 114 kg live weight.

No significant differences were found among breeds or sexes in percentages of subcutaneous, intermuscular or body cavity fat.

The influence of ration had little effect on percentage of subcutaneous or body cavity fat but did produce differences in percentage intermuscular fat. Pigs fed the HE ration had a greater percentage (15.3%) of intermuscular fat than did those fed the LE ration (14.2%, $P = 0.05$).

Although the overall differences in fat distribution due to the influence of ration appeared minor, significant interactions ($P = 0.05$) did occur between live weight and ration. As shown in Table 14, those pigs fed the LE ration increased in % subcutaneous fat from 82.6% at 68 kg to 83.9% at 91 kg and then plateaued to 84% at 114 kg live weight. In the HE fed pigs percentage subcutaneous fat decreased from

TABLE 13: Subcutaneous, intermuscular and body cavity fat as a percent of total fat

	Live weight (kg)				Breed			Sex		Ration	
	23 ¹	68	91	114	D	H	Y	Barrows	Gilts	LE	HE
Subcutaneous	77.7	82.5 ^a	82.4 ^a	84.3 ^b	82.7	82.7	83.8	83.5	82.5	83.5	82.6
Intermuscular	18.1	15.7 ^a	15.2 ^a	13.4 ^b	15.3	15.0	13.9	14.3	15.2	14.2 ^a	15.3 ^b
Body Cavity	4.2	1.8 ^a	2.5 ^b	2.3 ^b	2.0	2.3	2.3	2.1	2.2	2.3	2.1

¹ Not included in statistical analysis.

a,b, means within the same classification having different superscripts, differ significantly at P<0.05 or P<0.01.

TABLE 14: Interaction of ration and live weight
on % subcutaneous fat

Live weight (kg)	68	91	114
Ration			
LE	82.6	83.9	84.0
HE	82.4	80.8	84.5

TABLE 15: Interaction of ration and live weight
on % intermuscular fat

Live weight (kg)	68	91	114
Ration			
LE	15.5	13.6	13.5
HE	15.9	16.7	13.3

82.4% at 68 kg to 80.8% at 91 kg and then increased to 84.5% at 114 kg live weight. Opposite changes in % intermuscular fat occurred at each live weight (Table 15). Pigs fed the HE ration increased in % intermuscular fat from 15.9% at 68 kg live weight to 16.7% at 91 kg live weight and then decreased to 13.3% at 114 kg live weight.

Because of the differences in fat percentages for the main effects there was some interest in determining the distribution of hind or front percentages within the depots. Table 16 presents the percentage of hind and front fat distribution within each of the three fat depots. The 23 kg group is included in the table but was not included in the statistical comparisons. The greatest changes again occurred between 23 and 68 kg live weight. After 68 kg live weight the distribution as to hind and front remained fairly constant within the major depots. The only significant difference, as weight increased, was in the distribution of body cavity fat. After 91 kg live weight % hind body cavity fat decreased while % front body cavity fat increased.

Ration apparently had no influence on fat distribution within the fat groups but breed and sex effects were observed in the distribution of intermuscular fat. Duroc x Yorkshire pigs had a greater ($P < 0.05$) percentage of hind intermuscular fat and smaller percentage of front intermuscular fat than Hampshire x Yorkshire or Yorkshire x Yorkshire pigs which were equal. Barrows had a greater percentage of hind and a smaller percentage of front intermuscular fat than did gilts ($P < 0.05$).

Two significant interactions ($P < 0.05$) occurred between breed and sex for body cavity fat and live weight and sex for intermuscular fat (Tables 17 to 20). Duroc x Yorkshire and Hampshire x Yorkshire

TABLE 16: Hind and front subcutaneous, intermuscular and body cavity fat as percent of their respective totals

	Live weight (kg)				Breed			Sex		Ration	
	23 ¹	68	91	114	D	H	Y	Barrows	Gilts	LE	HE
Subcutaneous											
Hind	51.2	54.4	52.7	53.4	52.4	54.0	54.0	53.3	53.7	53.7	53.2
Front	48.7	45.6	47.3	46.6	47.5	46.0	46.0	46.7	46.3	46.2	46.8
Intermuscular											
Hind	41.6	34.2	33.4	34.5	37.6 ^a	33.3 ^b	31.1 ^b	35.2 ^a	32.8 ^b	32.9	35.1
Front	58.4	65.8	66.6	65.6	62.4 ^a	66.7 ^b	68.9 ^b	64.8 ^a	67.1 ^b	67.1	64.8
Body Cavity											
Hind	77.3	70.1 ^a	73.1 ^a	66.2 ^b	71.0	67.7	70.7	71.5	68.1	68.7	70.9
Front	22.2	29.9 ^a	26.9 ^a	33.8 ^b	29.0	32.3	29.3	28.5	31.9	31.3	29.1

¹ Not included in means comparisons.

a,b Means within the same classification having different superscripts, differ significantly at P<0.05 or P<0.01.

TABLE 17: Interaction of breed and sex on % hind body cavity fat

Breed	D	H	Y
Sex			
Barrow	76.6	68.6	69.2
Gilt	65.4	66.7	72.2

TABLE 18: Interaction of breed and sex on % front body cavity fat

Breed	D	H	Y
Sex			
Barrow	23.4	31.4	30.8
Gilt	34.6	33.3	27.8

TABLE 19: Interaction of live weight and sex on % front intermuscular fat

Live weight (kg)	23	68	91	114
Sex				
Barrow	55.6	63.2	64.6	66.6
Gilt	61.3	68.4	68.5	64.5

TABLE 20: Interaction of live weight and sex on % hind intermuscular fat

Live weight (kg)	23	68	91	114
Sex				
Barrow	44.4	36.8	35.4	33.4
Gilt	38.7	31.6	31.5	35.5

barrows had a greater percentage of hind body cavity fat and smaller percentage of front body cavity fat than did gilts (Tables 17 and 18). This pattern was reversed for the Yorkshire x Yorkshire barrows and gilts.

Interactions involving sex and live weight indicated that the percentage of the intermuscular fat in the front quarter increased in barrows from 23 to 114 kg live weight (Table 19). In gilts a similar increase occurred from 23 to 68 kg but from 68 to 91 kg a plateau occurred and from 91 to 114 kg there was a decrease in the percentage of the intermuscular fat in the front quarter in gilts. A mirror image effect naturally occurred in the percentage of the intermuscular fat in the hind quarter (Table 20).

D) Discussion

The trend towards lean meat production in more recent years has stimulated considerable interest in fat deposition in the carcass of pigs. Selection has been directed toward the reduction of subcutaneous fat by backfat measurements assuming that a change in one fat depot would be followed by similar changes in all depots. Considerable doubt about this relationship now prevails and while the overall pattern of fat deposition as described by earlier workers (Callow, 1947, 1948; Hammond and Murray, 1937) does not appear to have changed appreciably there appears to be an independence of fat deposition in each of the depots as well as an unpredictable sensitivity within each depot towards genetic and environmental influences.

In the present data as live weight increased % subcutaneous fat increased, % intermuscular fat decreased and % body cavity fat

remained relatively constant. These changes in fat distribution were not simultaneous however. Regression analysis of this data (Table 21) showed that correlations between fat depots varied from one live weight to another. Correlations between fat depots were highest and most constant at 23 kg live weight but fluctuated at the heavier weights indicating a differentiation in fat deposition among the three depots.

The different response among depots was a reflection of a differential deposition between front and hind quarters within each of the depots. Between 23 and 68 kg live weight % hind subcutaneous fat, front intermuscular fat and front body cavity fat increased while % front subcutaneous fat, hind intermuscular fat and hind body cavity fat decreased. By 68 kg live weight the pattern of deposition within each depot was essentially complete and as live weight increased beyond this point differentiation of fat deposition appeared to follow a pattern of least resistance. In the hind quarter the presence of large, terminally-attached muscles deterred large deposits of intermuscular fat to a greater degree than the smaller, more diffusely attached muscles of the front quarter. Subcutaneous fat was more readily deposited over the hind quarter. Body cavity fat was more easily accommodated in the spacious thorax area than the constricted kidney area.

Coupled with this differential deposition was the sensitivity towards genetic and environmental influences. Contrary to the overall pattern of fat deposition, the fatter Duroc x Yorkshire pigs contained a higher percentage of hind intermuscular fat, a lower percentage of front intermuscular fat and a slightly lower percentage of hind

TABLE 21: Correlations of subcutaneous, intermuscular and body cavity fat at 23, 68, 91 and 114 kg live weight

Live weight (kg)	23		68		91		114	
	(2)	(3)	(2)	(3)	(2)	(3)	(2)	(3)
Fat depots								
(1) Intermuscular	.645	.603	.272	.229	.618	.259	.496	.232
(2) Subcutaneous	-	.879	-	.423	-	-.147	-	.402
(3) Body cavity		-		-		-		-

subcutaneous fat than did the other breed groups. Between sexes, barrows, which were fatter than gilts, had the greater percentage of hind intermuscular fat while gilts had the greater percentage of front intermuscular fat. On the HE ration intermuscular fat showed a greater rate of deposition up to 91 kg live weight than did subcutaneous fat. After 91 kg these rates were reversed. On the LE ration, % subcutaneous fat increased and intermuscular fat decreased up to 91 kg while both remained constant thereafter. In each case those pigs with a predisposition to fatten quickly deviated from the normal pattern of fat deposition.

With the apparent differentiation in fat deposition between and within depots the question arises how the reduction of fat in the carcass might be best accomplished. As can be seen from Table 22, backfat measurements are most highly correlated with subcutaneous fat and explain only a small part of the variance found in intermuscular fat, body cavity fat or total muscle.

Even though reducing subcutaneous fat may reduce the major part of the total fat in the carcass there is little indication that proportionate reductions would occur in the other depots. Reduction in one depot may not affect the other depots or it may have an inverse effect. On comparing the Pietrain and Large White breeds King (1970) observed that Pietrain crosses had more muscle and less subcutaneous fat than the Large Whites or their crosses but the amount of intermuscular fat in the carcass was not different. On the other hand Callow (1961) observed that within "beef type" animals those breeds with the lower subcutaneous fat had higher intermuscular fat and that "dairy type" animals were lower in both subcutaneous and

TABLE 22: Correlations of shoulder loin and backfat measurements
with fat groups and total muscle

Live weight (kg)	68			91			114		
Backfat measure	Sh	Bk	Ln	Sh	Bk	Ln	Sh	Bk	Ln
Fat depots									
Sucutaneous	.661	.794	.702	.685	.705	.693	.679	.514	.284
Intermuscular	.351	.468	.409	.197	.362	.252	.676	.443	.336
Body cavity	.128	.306	.275	.350	.349	.264	.708	.378	.320
Muscle	-.336	-.462	-.461	-.512	-.608	-.535	-.600	-.615	-.646

intermuscular fat but were highest in mesenteric and caul fat. Doornenbal (1967) and Duniec et al. (1961) have indicated that in pigs the genetic correlation between fat depots could allow for independent selection within each depot. If this is so then it is quite unlikely that reducing backfat will reduce the proportion of intra or intermuscular fat in retail cuts. Means must therefore, be found to reduce the fat in each depot. It is obvious that experiments concerned with backfat selection must take into consideration not only the simple reduction of subcutaneous fat but the entire question of fat deposition.

IV. Bone Growth and Distribution

A) Introduction

Previous studies of bone growth in sheep and pigs (Hammond, 1932; McMeekan, 1940, a, b, c) have suggested an anterior-posterior pattern of skeletal growth as well as a centripetal pattern of growth within the limbs. It has also been suggested that growth in length preceeds that in circumference and that plane of nutrition has a decided effect on circumference in the later stages of growth. The present study on tissue development and muscle and fat distribution in pigs indicated a definite differentiation of growth within and between these tissues. Because of the possible dependence of muscle growth on bone growth it appeared necessary to determine if there was a differentiation between length and circumference growth and if the point of differentiation in bone distribution corresponded to that of muscle distribution.

The present chapter presents the data of individual bone measurements and bone distribution in pigs as affected by live weight, breed sex and ration.

B) Materials and Methods

The design of the experiment and allotment of animals was the same as previously presented. Because of incomplete bone data 3 of the pigs slaughtered at 23 kg live weight were not included in this study. The total number of pigs used therefore was 106, with 14 slaughtered at 23 kg and 92 slaughtered at 68, 91 or 114 kg live weight.

Half carcasses were dissected into individual muscles, fat and

bones. Bones were weighed to the nearest gram. Vertebrae bones were grouped as to cervical, thoracic or lumbar while sternum and rib cartilage were weighed together. All other bones were weighed individually. Length and circumference measurements were made on the scapula, humerus, radius and ulna, femur and tibia. Length measurements represented the greatest distance between proximal and distal points of each bone while circumference measurement represented the narrowest point on the shaft of each bone.

Multiway analysis of variance and comparison of means for the data were carried out according to the methods of Steel and Torrie (1960).

C) Results

The influence of live weight, breed, sex and ration on the increase in length, circumference and weight of the scapula, humerus, radius and ulna, femur and tibia are illustrated in Figures 3-5 and presented in Table 23.

As live weight increased from 23 to 114 kg bone length increased in a linear fashion relative to live weight up to 91 kg after which growth rate decreased slightly for all bones except the humerus (Fig. 3). Circumference of each bone increased most rapidly between 23 and 68 kg live weight after which circumference increased at a decreasing rate (Fig. 4). Weight for all bones increased significantly in a linear pattern over all live weights (Fig. 5).

There appeared to be little difference among breeds in length, circumference or weight of the individual bones measured (Table 23). The only significant differences observed were for radius and ulna

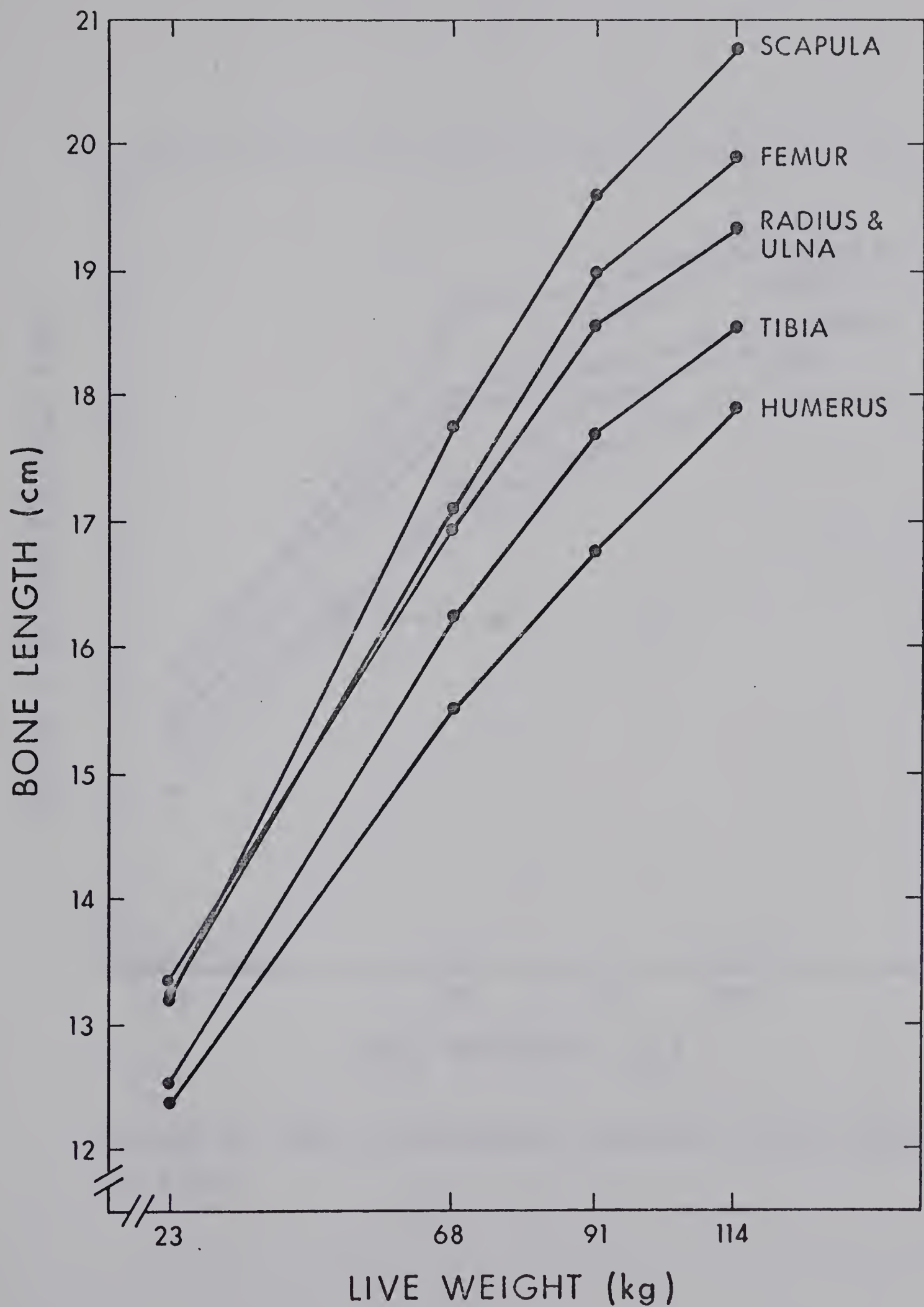


FIGURE 3 BONE LENGTH RELATIVE TO LIVE WEIGHT IN PIGS.

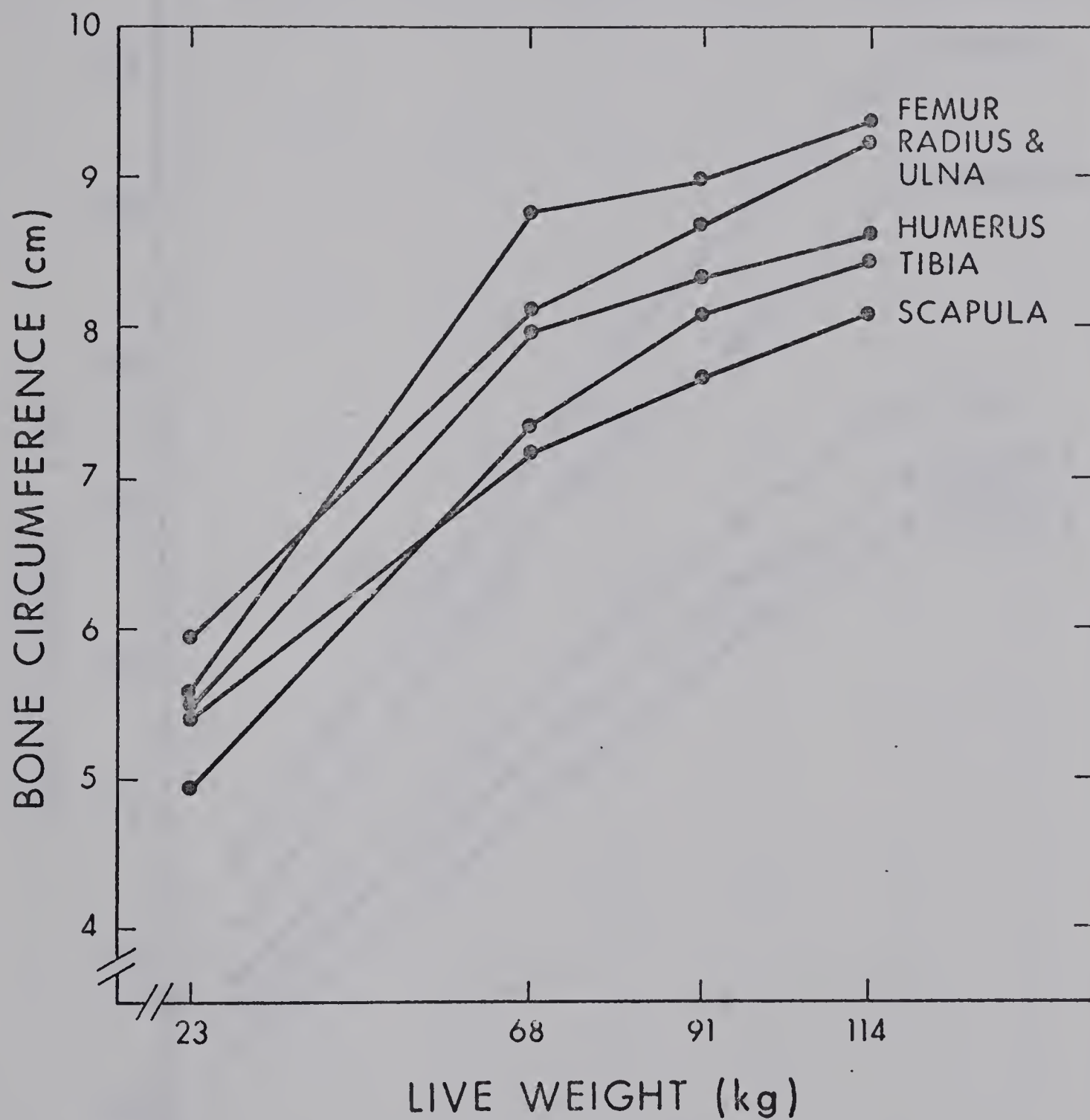


FIGURE 4 BONE CIRCUMFERENCE RELATIVE TO LIVE WEIGHT IN PIGS.

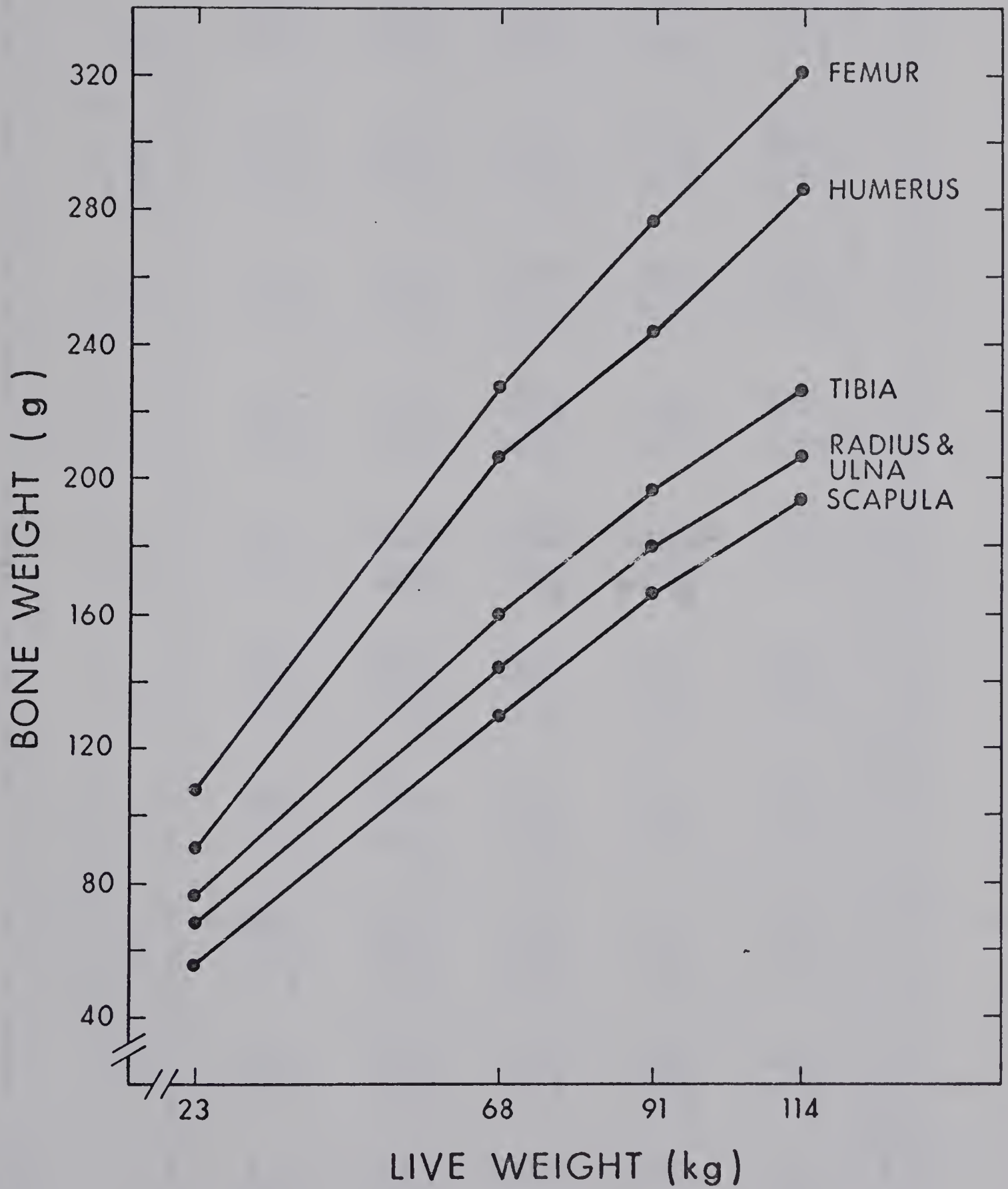


FIGURE 5 BONE WEIGHT RELATIVE TO LIVE WEIGHT IN PIGS.

TABLE 23: Length, circumference and weights of 5 bones as influenced by weight, breed, sex and ration

	Live weight (kg)				Breed			Sex			Ration	
	23 ¹	68	91	114	D	H	Y	Barrow	Gilt	LE	HE	
Scapula												
Length.....cm	13.16	17.76 ^a	19.60 ^b	20.76 ^c	19.21	19.64	19.27	19.11 ^a	19.64 ^b	19.67 ^a	19.08 ^b	
Circumference...cm	5.41	7.18 ^a	7.67 ^b	8.08 ^c	7.63	7.58	7.71	7.64 ^a	7.65 ^b	7.69	7.60 ^b	
Weight.....g	57.86	130.50	167.16	195.49 ^c	167.47	166.80	158.87	155.46 ^a	173.31 ^b	157.25 ^a	171.52 ^b	
Humerus												
Length.....cm	12.37	15.52 ^a	16.79 ^b	17.92 ^c	16.74	16.42	17.06	16.54	16.95	16.87	16.62	
Circumference...cm	5.49	7.99 ^a	8.36 ^{ab}	8.63 ^c	8.23	8.44	8.31	8.32	8.33	8.33	8.32	
Weight.....g	90.93	207.72	244.32	286.72 ^c	248.81	236.07	253.87	243.58	248.92	248.50	244.01 ^a	49-
Radius and Ulna												
Length.....cm	13.34	16.94 ^a	18.57 ^b	19.33 ^c	18.28	18.07	18.48	18.14	18.42	18.45	18.11	
Circumference...cm	5.95	8.14 ^a	8.70 ^b	9.24 ^c	8.95 ^a	8.56 ^b	8.56 ^b	8.59	8.79	8.70	8.68	
Weight.....g	68.71	144.26	180.84	207.66 ^c	182.65	174.68	175.42	174.03	181.14	174.78	180.59	
Femur												
Length.....cm	13.23	17.10 ^a	18.99 ^b	19.94 ^c	18.51	18.66	18.88	18.43 ^a	18.94 ^b	18.91	18.45	
Circumference...cm	5.58	8.75	8.99 ^b	9.42 ^c	8.87	9.25	9.03	9.06	9.05	9.05	9.05	
Weight.....g	108.00	227.74	227.07	321.77 ^c	269.77	272.86	283.97	272.36	278.71	273.16	277.90	
Tibia												
Length.....cm	12.52	16.25 ^a	17.70 ^b	18.53 ^c	17.57	17.28	17.64	17.26 ^a	17.73 ^b	17.61	17.38	
Circumference...cm	4.95	7.35 ^a	8.11 ^b	8.46 ^b	7.72	8.07	8.13	8.08	7.86	8.05	7.89	
Weight.....g	77.36	160.48	196.00	227.81 ^c	198.72 ^a	186.67 ^b	198.89 ^a	191.32	198.21	195.51	194.02	

¹ Means for pigs slaughtered at 23 kg not included in statistical comparisons.

a,b,c Means within the same classification having different superscripts differ significantly at P<0.05 or P<0.01.

circumference and tibia weight. Duroc x Yorkshire pigs had a greater radius and ulna circumference ($P < 0.05$) than Hampshire x Yorkshire or Yorkshire x Yorkshire pigs which were equal. Tibia weight in the Hampshire x Yorkshire pigs was less ($P < 0.05$) than that in either the Duroc x Yorkshire or Yorkshire x Yorkshire pigs.

Differences between barrows and gilts occurred in the length and weight of the scapula and in the length of the femur and tibia. In each instance gilts had a significantly greater length and weight than barrows ($P < 0.05$). Although there was no significant difference observed between sexes for femur weight a significant interaction did occur between sex and live weight (Table 24). At 68 kg live weight femur weight for barrows exceeded that for gilts by 9 g but at 114 kg live weight gilts exceeded barrows by 24 g in femur weight.

Ration did not influence the length, circumference or weight of the majority of bones measured. The only bone affected significantly was the scapula which appeared to have a greater length as a result of the LE ration and a greater weight as a result of the HE ration ($P < 0.05$) (Table 23).

Comparisons of weight-length (WL) ratios, have suggested an early growth in bone length followed by a later circumference growth (McMeekan, 1940a; Whyte, 1958). Bones from this experiment were compared on this basis as well as by weight-circumference (W/C) and length-circumference (L/C) ratios (Table 25). The W/C and W/L ratios revealed little about the growth of bone other than that bone weight increased at a greater rate than either length or circumference ($P < 0.01$). On the other hand, L/C ratios did reveal a pattern of length and circumference growth. Slight decreases in the L/C ratio

TABLE 24: Interaction of sex and
live weight on femur weight (g)

Sex	Live weight (kg)		
	68	91	114
Barrow	232	275	310
Gilt	223	279	334

TABLE 25: Ratios of length, circumference and weight for 5 bones as influenced by live weight, breed sex and ration

	Live weight (kg)				Breed			Sex			Ration	
	23 ¹	68	91	114	D	H	Y	Barrow	Gilt	LE	EE	
Scapula												
L/C	2.44	2.48	2.55	2.59 ^c	2.51 ^a	2.59 ^b	2.51 ^c	2.51 ^a	2.57 ^b	2.57 ^a	2.51 ^b	
W/C	10.69	18.23 ^a	21.88 ^b	24.60 ^c	21.88 ^a	22.21 ^b	20.61 ^c	20.37 ^a	22.77 ^b	20.54 ^a	22.60 ^b	
W/L	4.40	7.38 ^a	8.60 ^b	9.53 ^c	8.73	8.57	8.21	8.12 ^a	8.89 ^b	7.99 ^a	9.02 ^b	
Humerus												
L/C	2.26	1.96 ^a	2.01 ^a	2.08 ^b	2.02	1.94	2.07	2.00	2.03	2.03	2.00	
W/C	16.60	26.21 ^a	28.31 ^a	33.29 ^b	29.63	28.08	30.60	29.42	29.45	29.81	29.05	
W/L	7.34	13.41	14.38 ^a	16.04 ^b	14.65	14.46	14.72	14.70	14.52	14.69	14.53	
Radius & Ulna												
L/C	2.24	2.09	2.13 ^b	2.10 ^c	2.04 ^a	2.11 ^a	2.17 ^b	2.10	2.11	2.13	2.08	
W/C	11.53	17.82 ^a	20.76 ^b	22.84 ^c	20.29	20.57	20.55	20.22	20.73	20.18 ^a	20.77 ^b	
W/L	5.15	8.55	9.77 ^b	10.91 ^c	9.97	9.76	9.49	9.61	9.87	9.49 ^a	10.00 ^b	
Femur												
L/C	2.37	2.01 ^a	2.11 ^b	2.15 ^c	2.10	2.04	2.13	2.07	2.11	2.09	2.08	
W/C	19.38	26.68 ^a	30.99 ^b	34.64 ^c	30.52	29.88	31.92	30.49	31.06	30.26	31.28	
W/L	8.16	13.35	14.76	16.24	14.68	14.72	14.96	14.80	14.77	14.48	15.09	
Tibia												
L/C	2.53	2.24	2.19 ^b	2.22 ^c	2.28	2.15	2.22	2.17	2.27	2.19	2.25	
W/C	15.62	22.12 ^a	24.36 ^b	27.45 ^c	25.65	23.41	24.88	23.96	25.32	24.24	25.05	
W/L	6.17	9.91 ^a	11.14	12.38 ^c	11.33	10.90	11.20	11.07	11.21	11.09	11.19	

¹ Means for pigs slaughtered at 23 kg not included in statistical comparisons.
a,b,c Means within the same classification having different superscripts differ significantly at P<0.05 or P<0.01.

between 23 and 68 kg live weight indicated a slightly greater growth rate for circumference than for length in all bones except the scapula. After 68 kg live weight L/C ratios remained relatively constant indicating similar growth rates for length and circumference.

The only influence breed appeared to have on L/C ratios was for radius and ulna. Yorkshire x Yorkshire pigs exceeded both Hampshire x Yorkshire and Duroc x Yorkshire pigs in radius and ulna L/C ratio ($P < 0.05$).

The influence of sex appeared to be limited to the scapula W/C and W/L ratios while ration affected both scapula W/C and W/L ratios and the W/L ratio of the radius and ulna. Gilts exceeded barrows and pigs fed the HE ration exceeded those fed the LE ration in each case ($P < 0.05$).

In addition to the differentiation in length and circumference growth rates there was considerable interest in determining if a pattern of differentiation existed for bone distribution in the skeleton.

To determine the pattern of distribution individual bone groups dissected from one half the carcass were expressed as a percentage of total bone in the side (Table 26). As live weight increased the percentage of the total bone in the carcass decreased but % bone within the hind and front quarters remained relatively constant. Of the individual bone groups only the lumbar vertebrae showed a significant percent increase as live weight increased above 68 kilograms ($P < 0.05$). The humerus, femur, tibia and hock bones all decreased significantly in percentage as live weight increased ($P < 0.05$). Although there were no significant differences, the scapula, radius and ulna,

TABLE 26: Influence of live weight, breed, sex and ration on bone distribution in pigs expressed as a percentage of either carcass or total bone weight

	Live weight (kg)				Breed		Sex		Ration		
	23 ¹	68	91	114	D	H	Y	Barrow	Gilt	LE	RE
Total bone (% of carcass)	13.2	10.5 ^a	9.9 ^b	9.2 ^c	9.7	9.7	10.1	9.6	10.1	10.1	9.6
Head bone	47.61	44.55	44.58	44.79	44.75	43.98	45.19	44.93	44.35	44.12	45.16
Front Bone	52.39	55.45	55.42	55.21	55.25	56.02	54.81	55.07	55.65	55.98	54.84
<u>Individual bones (% of total bone)</u>											
Scapula	5.51	6.00 ^a	6.04 ^b	5.96 ^b	6.14 ^a	6.25 ^a	5.62 ^b	5.83 ^a	6.18 ^b	5.72 ^a	6.25 ^b
Humerus	8.68	9.52 ^a	8.67 ^b	8.58 ^b	9.05 ^a	8.78 ^a	8.94 ^b	9.14	8.71	9.05	8.80
Radius & Ulna	6.55	6.64	6.51	6.35	6.69 ^a	6.54 ^a	6.26 ^b	6.55	6.45	6.39	6.61
Carpus	1.22	1.36	1.11	1.10	1.19	1.16	1.22	1.23	1.15	1.27	1.12
Pelvis	10.30	10.30 ^a	10.31 ^{ab}	10.43 ^b	10.21	10.45	10.37	10.40	10.29	10.24	10.45
Femur	10.31	10.47 ^a	10.08 ^b	9.73 ^b	10.01	10.19	10.07	10.26	9.92 ^a	10.00	10.18
Tibia	7.38	7.38 ^a	7.07 ^b	6.91 ^b	7.32	6.99	7.06	7.19	7.05	7.12	7.12
Hock bones	3.78	3.24 ^a	3.19 ^a	2.26 ^b	2.76	3.14	2.79	2.93	2.86	2.65	3.14
Patella	.60	.78	.74	.78	.74	.79	.77	.78	.75	.77	.76
Atlas	1.13	1.48	1.53	1.48	1.49	1.46	1.54	1.47	1.53	1.52	1.47
Cervical Vertebrae	4.83	6.01	6.10	6.73	6.02	6.24	6.58	6.01	6.55	6.60	5.96
Thoracic Vertebrae	15.49	11.29 ^a	11.87 ^b	11.70 ^b	11.36	10.72	12.77	11.51	11.73	12.03	11.21
Lumbar Vertebrae	7.78	7.01 ^a	7.79 ^b	8.39 ^b	7.98	7.15	8.06	7.57	7.89	7.74	7.72
Ribs	12.34	13.86	14.48	14.97	14.58 ^a	14.93 ^b	13.80 ^a	14.47	14.40	14.16	14.71
Sternum & Rib cartilage	4.10	4.63	4.49	4.62	4.44	5.18 ^b	4.13 ^a	4.64	4.53	4.72	4.45

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¹ Means for pigs slaughtered at 23 kg not included in statistical comparisons.

a,b,c Means within the same classification having different superscripts differ significantly at P<0.05 or P<0.01.

thoracic vertebrae and carpus tended to decrease in percentage slightly as live weight increased while the percentage pelvis, patella, atlas, cervical vertebrae, ribs and sternum and rib cartilage tended to increase slightly.

Breed appeared to influence the percentage of scapula radius and ulna and sternum and rib cartilage. Yorkshire x Yorkshire pigs had a smaller percentage of scapula and radius and ulna than Duroc x Yorkshire or Hampshire x Yorkshire pigs while Hampshire x Yorkshire pigs had the greater percentage of sternum and rib cartilage ($P < 0.05$). Gilts had a greater percentage of scapula than did barrows and pigs fed the HE ration a greater percentage than those fed the LE ration ($P < 0.05$). Interactions between sex and ration for percentage scapula occurred and are illustrated in Table 27. Barrows had a greater percentage scapula on the HE than on the LE ration ($P < 0.05$) while gilts were affected about equally on the two rations.

D) Discussion

Previous studies on bone growth in pigs have indicated that growth in bone circumference is proportionately greater than that in length after a certain stage of development of the animal. McMeekan (1940a) indicated that this differentiation took place after 20 weeks of age (52 kg live weight) and Cuthbertson and Pomeroy (1962) reported similar patterns for length and circumference growth between 50 and 92 kg carcass weight.

In the present experiment the data supported a differentiation between length and circumference growth but suggested that this differentiation may have occurred at much earlier live weights than

TABLE 27: Interaction of sex and
ration on % scapula

Sex	Ration	
	HE	LE
Barrow	6.05	5.40
Gilt	6.31	6.26

previously reported. Differences between the relative growth rates for length and circumference were detected between 23 and 68 kg live weight but not at heavier weights.

The influence of breed and sex on length, circumference and weight of the individual bones was inconsistent and confounded by interactions with live weight. It is doubtful that individual bone differences due to these major effects would contribute to economic differences within retail cuts.

When studying the effects of plane of nutrition on bone growth McMeekan (1940b, c) found that a high plane of nutrition caused a greater thickness and low plane of nutrition a greater length in bones. It was also suggested that plane of nutrition affected the later developing circumference more than the earlier developing length. Although the rations used here may not have been as restrictive on growth as those used by McMeekan, there appeared to be little difference in length and circumference growth between rations.

Studies in both sheep and pigs have reported an earlier development of the distal limb bones than the proximal bones and a later development of the lumbar bones than the cervical or thoracic bones (Hammond, 1932; McMeekan, 1940a; Cuthbertson and Pomeroy, 1962).

In this report no accurate comparison of a centripetal pattern of growth within the limb bones could be made with earlier studies since all of the bones studied were located more in the proximal than distal region of the limbs. However, an anterior-posterior pattern of skeletal development was observed. The decreasing percentage of thoracic vertebrae indicated a decreasing anterior growth while the increasing percentages of ribs and lumbar vertebrae indicated an

increasing posterior growth. But, as was found by Cuthbertson and Pomeroy (1962), the cervical vertebrae tended to increase at heavier live weights rather than decrease suggesting a later stage of maturity for this bone group than suggested by earlier reports. Cuthbertson and Pomeroy also reported the growth of thoracic vertebrae as exceeding that of lumbar vertebrae between 68 and 92 kg carcass weight but no such conclusion could be drawn from these data.

There appeared to be little consistent effect of breed, sex or ration on the distribution of bone in the carcass indicating the rather stable position of bone in the carcass.

Although the data presented were not analyzed in detail as to the relationship of muscle and bone growth it was interesting to note that the differentiation in bone distribution being essentially completed at or before 23 kg live weight corresponded to the differentiation of muscle distribution (Table 12). After 68 kg live weight relatively little change occurred in muscle or bone distribution.

GENERAL SUMMARY AND CONCLUSIONS

The objectives of this study were to determine the patterns of development and distribution of the major body tissues in swine and to determine what effects live weight, breed, sex and ration had on these patterns.

Tissue Development

A normal pattern of tissue growth was shown to occur with bone growth being relatively slow and muscle growth relatively fast. Fat deposition paralleled muscle growth from 68 to 91 kg live weight after which fat deposition exceeded muscle growth in absolute amount. Breed of sire tended to influence the carcass, muscle and fat weight per day of age as well as the proportions of lean and fat in the carcass.

Gilts had more muscle per day of age and a greater percentage of muscle and less of fat than did barrows. Barrows had a greater carcass weight and more fat per day of age than gilts. The LE ration resulted in higher percentage of muscle and lower percentage of fat in the carcass than did the HE ration. At all slaughter weights, the differences in the proportions of muscle, fat and bone between barrows and gilts were similar to the differences resulting from the HE and LE rations.

Carcasses from gilts slaughtered at 114 kg live weight were equal in composition to those from barrows slaughtered at 91 kilograms. Similarly, pigs fed the LE ration at 114 kg had equal carcass composition to HE fed pigs at 91 kilograms. The data indicated that there may be some justification for extending the weight range in the Canadian grading system such that carcasses of superior composition outside the present weight range would be recognized on their merit.

Some interactions occurred among breed, sex and ration groups reflecting differences in energy intake and partitioning of nutrients for tissue growth.

Muscle Growth and Distribution

Slight changes occurred in muscle distribution between 23 to 68 kg live weight with little change thereafter. Breed groups were quite similar except that Duroc x Yorkshire pigs had a significantly greater percentage of muscle in the spinal group.

The influence of sex appeared to vary relative to live weight with gilts maturing at earlier weights than barrows. Ration influence was negligible except for the distal thoracic limb group which had a slightly greater percentage of muscle on the HE ration than on the LE ration.

Unexplained interactions between sex and ration and sex and breed effects occurred for the thorax to thoracic limb muscle group.

Comparisons of the present pig data with that from cattle indicated that in pigs diphasic growth patterns may not be as pronounced as in cattle and that individual muscles may be growing proportionate to total muscle very early in life. There seemed to be little evidence to indicate that selection pressures have had any influence on changing the muscle distribution in swine.

Fat Deposition and Distribution

As live weight increased from 23 to 114 kg a differentiation between depots occurred; % subcutaneous fat increased and % inter-muscular and body cavity fat decreased. Within each depot differential deposition between front and hind quarters was most noticeable

between 23 and 68 kg live weight. During this period the major proportion of intermuscular and body cavity fat was deposited in the front quarter while a greater proportion of the subcutaneous fat was deposited in the hind. After 68 kg live weight little change occurred in proportion of front to hind within the major fat depots although the proportion of body cavity fat in the front quarter increased at the expense of the hind.

Deviations from the overall pattern of fat deposition were indicated by certain interactions between breed, sex and weight.

The data indicated an independence of fat deposition among the major depots. It appeared that a reduction of fat in one depot would not necessarily be paralleled by a reduction in the other depots.

Bone Growth and Distribution

Length and circumference had proportionate rates of growth between 23 and 68 kg live weight with the rate for circumference slightly exceeding that for length. At live weights above 68 kg, growth in length paralleled that in circumference. The effects of breed, sex and ration on bone length and circumference were minor and inconsistent.

An anterior-posterior pattern of skeletal growth was observed while any centripetal pattern of limb growth appeared to have been essentially completed at or before 23 kg live weight. Differentiation in bone distribution paralleled that found in muscle distribution.

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